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Review of sustainable biomass pellets production – A study for agricultural residues pellets' market in Greece

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ABSTRACT

Agro residues constitute the biggest source of biomass in Greece. Although large amounts of agricultural residues are produced in Greece each year, their contribution towards meeting national energy demand has remained rather low due to inefficient and unplanned use. These residues have low heating value per unit volume and high transportation and storage costs when used in as received condition; these difficulties can be largely overcome through densification which is an effective approach for using residues efficiently. Densification offers an opportunity to make biomass easier to handle and transport. The cost of the endeavor is a challenge. However, there is a need to consider a system that operates year around with several biomass materials. The investigation in the Greek and the international market shows that mixed biomass pellets are promising fuels and with the appropriate support these fuels have many prospects for the future. The use of biomass pellets would not only create new market opportunities for agricultural industries, it would also reduce dependence on coal, as well as the greenhouse gas emissions associated with coal use.

Contents

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1. Introduction

To make biomass available for various applications, some problems that relate to the original form of biomass should be solved. Due to the high moisture content, the unspecified form and size and the low specific weight of biomass, it is very difficult to be treated, transported, stored and used in its original form. A solution to these problems is the densification of biomass in pellets. When biomass is concentrated its specific weight increases from 40–200 kg m^{-3} to 600–800 kg m^{-3}. Consequently, the densification of biomass could reduce the costs of transportation, handling and storage. Due to its uniform shape and size, densified products (pellets) can be easily used, stored and even further treatment.

By the term *biomass* we call any material produced by organisms of animal and plant origin (such as wood, agricultural residues, and animal residues) and can be used as fuel for energy production. Biomass is mainly composed of carbon and oxygen and in lower percent from of hydrogen, sulfur, nitrogen and ash. Biomass, in the energy production industry, refers to living and recently dead biological material that can be used as fuel. Biomass may also include biodegradable wastes that can be burnt as fuel. It is grown from a number of plants, including miscanthus, switchgrass, hemp, wheat straw, corn, poplar, willow and sugarcane tops. Biomass is part of the carbon cycle, where carbon from the atmosphere is converted into biological matter by photosynthesis. Upon combustion, the carbon goes back into the atmosphere or soil. This happens over a relatively short timescale, and plant matter used as a fuel can be constantly replaced by planting for new growth. Therefore, a reasonably stable level of atmospheric carbon results from its use as a fuel. The main advantages of using biomass in order to produce energy are:

- Zero balance of carbon dioxide (CO_2).
- Minimal presence of sulfur.
- The dependence on imported fuels is reduced.
- Employment growth in rural areas.

On the other side, there are many disadvantages that have to be considered:

- Increased volume and high moisture content.
- The dispersal and seasonal production of biomass.
- Difficulties in collecting, transporting and storing of biomass.
- High equipment costs.

The co-firing of biomass and non-recyclable commercial, municipal and industrial waste with coal represents one of the nearest-term and lowest-cost options for carbon dioxide reduction in the electrical power sector. Compared to burning coal by itself, it has proven to be a low-capital investment for utilities, using existing coal-fired plants to burn biomass and non-recyclables that are more environmentally friendly with lowered pollutant emissions. Co-firing has been demonstrated successfully in more than 150 installations worldwide. With its plant numbers continuing to increase, the trend could soon evolve into the preferred and most standard practice for reducing carbon dioxide emissions in power facilities. For co-firing plants pellets are the most appropriate form of feeding biomass.

Pellet is a cylindrical organic fuel made by the compression of biomass. Biomass usually comes from agricultural residues, forest by-products and wood industries. Biomass pellets are competitive against oil fuels, natural gas and electricity not only because of the low cost but also because they are ease in usage and storage. Pellets are an excellent and inexpensive solution to replacing oil; they are renewable and inexhaustible and do not pollute the environment. Pellets can be produced from one type or mixed biomass.

Mixed biomass pellets (MBP) have a great potential in enlarging the use of biomass for energy conversion, particularly in central and south European countries. With the exhaustion of biomass residues for wood pellets production (particularly sawdust) the production of MBP is of increasing interest for project developers and biomass producers. Hence, in this market not the availability of the biomass resource is the most critical factor, but the availability of a sales market itself [1].

As MBP are a newcomer on the pellet market, as national quality standards for MBP do not exist (reference only on CEN standards) and as they will hardly be used in domestic small scale applications, trade and market structures for MBP will differ from wood pellets. For most European countries a market for MBP does simply not exist. Activities are mainly happening on bilateral agreements between producer and consumer. The use of biomass pellets would not only create new market opportunities for the forest and agricultural industries, it would reduce dependence on coal, as well as the greenhouse gas emissions associated with coal use [1].

The energy sector has become crucial in making decisions and formulating policies relating to economic, social and technological issues. Thus far, it becomes more pronounced the need for objective, validated, organized and scientific data and information on environmentally friendly energy investments such as Renewable Energy Sources (RES). The purpose of this study is to investigate the pellet market in Greece and to study the production process of pellets issued from agro residues. Initially, a brief reference to the situation in the global market of pellets and the quality standards and the main markets of Europe is presented following by more detailed presentation of the situation in the Greek pellet market, the prices in Greece and Europe, the current legal and political framework applied in European countries and in Greece. Furthermore, a description of the overall production process, presenting important new and improved methods applied in the process of pelletization will be analyzed as well with their environmental and economic issues.

2. European legislative frame

The continuously increasing pellet consumption in the European countries made imperative the need of creation of legal frame for the use and the production of biomass. At the same time most of the governments are giving economic motives for the use of systems of pellets combustion. Some European countries are active in the respective national/regional regulations and/or equivalent quality labels. In most of the countries either these regulations are standards and quality labels for BHS and/or for biomass fuels. High capital cost and risk perception may hamper the growth of this green energy market and it is important to understand the local regulations, policies, incentives and quality labels in countries with established biomass heating market, in order to establish a balanced sustainable heat market [2].

Countries with well developed pellet industries, like Austria, Sweden and Germany, have developed their own pellet standards while other major producing regions, like Finland and Denmark, have chosen to anticipate for a common European standard for solid biofuels CEN/TS 14961 to be developed. This common pellet standard is being developed by technical committee 335 of the European Committee for Standardization (CEN). This means existing national standards will be harmonized but special national or regional requirements will still be respected. The common European standard is essentially the platform for a labeling program. It identifies which attributes will be mandatory to test and report and which will be voluntary. It also determines appropriate ranges or categories to report within each attribute. Generally limit values for bulk density, unit density, ash content, water content, calorific value, sulfur, nitrogen and chlorine are fairly similar [2].

3. State of the art for biomass pellets in some European countries

The availability of raw material, competitive prices and diversified energy policies favor development of a wood pellet industry in Europe. Sweden, Denmark, Germany and Austria have the most highly developed pellet markets. The others like Italy, Belgium, France and UK recently have been following that trend. In 2006 the production of pellets in Europe was about 4,500,000 tn, with Sweden, Austria and Germany as main producers [3].

3.1. Sweden

Sweden is the biggest European producer of wood pellets accounting for 1,458,000 tn in 2006. Total capacity of 35 pellet plants in Sweden is estimated for an over 1,600,000 tn/year (with 2 plants producing over 130,000 tn and 15 producing over 30,000 tn a year). The pellets distribution network is well established, with truck transport common for shorter distances, while sea shipping proving economical for longer distances [3].

The Swedish pellets market is the largest in the world. The numbers for 2006 show the consumption of approximately 1,670,000 tn of pellets, an increase by 4,400,000 tn from 2004. Sweden pellets make up a large proportion of the fuel market, with almost 60% being used in the large power stations, in district heating, combined heat and power plants as well as in private houses. In recent years, also industry boilers have been converted to pellet combustion. Biomass experts estimate that between 800,000 and 1,100,000 tn of raw material are annually available for pelletizing. Wood pellet production started in Sweden in 1982, however due to high production costs, low demand, and lack of combustion technology, the pellet fuel did not really take off until after 1992 when the Swedish government introduced a tax on fossil fuels (presently 59% for CO_2 on all fossil fuels). It became thus cheaper for utilities and private consumers to burn biofuels rather than oil, coal or gas. An important factor behind the fast growth was the fact that big utility (Stockholm Energy) invested in a large-scale pellet plant to secure its requirements of pellets before a conversion of its boilers [3].

3.2. Germany

The use of wood in the energy sector has developed continually and recently received extraordinary impetus due to the huge increases in oil and gas prices. Heating with CO_2-neutral wooden pellets has become a cost effective alternative to conventional fuels. So much use was made of the support options offered by the Federal Government that the budgetary funds were completely exhausted in 2005. In 2006, 160,000 applications have already been made 50% more than the total number supported in 2005. This has now exhausted the existing support funds. The support program is continuing, but it will use support rates which have been adapted to the rapid market development. The pellet production is developing into another economic mainstay for an increasing number of enterprises in the sawmilling and timber industry, often in addition to their own generation of heat or electricity based on bark and wood residues [3].

German wood pellet production is still relatively small. However, favorable tax laws for installation of biofuel combustion systems and large quantities of available wood fiber (7 million tn of scrap wood from sawmills and commercial timber alone) make Germany one of the most promising pellet markets in Europe. About 30% of the country is covered in woodland. Commercial wood pellet production has started in several locations in Germany in the last decade. Currently 32 processing facilities produce an estimated 550,000 tn of wood pellets, there of 420,000 tn for domestic consumption. The main sources for the raw material are saw dust, wood chips and other wood residues. The pellet producer German Pellets GmbH is going to increase pellet production in Germany. Thus it will be the biggest pellet producer in Europe. The production capacity for wood pellets is forecast to reach the 1,200,000 tn in 2010 [3].

3.3. Austria

In Austria, rapid growth of pellets market started in 1997 when the first systems were introduced into the market. The market for pellets in the residential sector in Austria is presently expanding rapidly. Several actors, quality standards and subsidies are supporting this development. Proven feeding and combustion technologies are available from many furnace manufacturers which ensure a fully automatic operation. In Austria pellets production is an attractive business for the wood-processing industry therefore it has been developing very dynamically [3].

In 2006, about 27 companies are producing pellets, three of them with a production capacity >70,000 tn/year. The total production capacity which amounts 600,000 tn/year is expecting to be increased in the years to come. According to the Austrian Energy Agency, for 2007 a production capacity of one million tonne of pellets is forecasted. In 2005, Austrian pellet plants produced approximately 450,000 tn of pellets and for 2006 the domestic pellets production raised above 600,000 tn. For 2007 a production capacity of one million tn of pellets is forecasted by the Austrian Energy Agency [3].

4. Biomass pellets state of the art in Greece

Even thought the Greek pellet market is still in initial stage comparatively with the other European countries, nevertheless certain efforts for the selection and organization of information aiming at the growth of Greek market have been undertaken. The effort began with the Greek participation into the European program “pellets for Europe”, expired in 2007 and followed by the program pellets@las in which Greece participates as well. “Pellets for Europe” provides technical and market information for pellet market actors and promotes pellet technologies across Europe.

The main aim for this European project is to support the development of the European pellet market. The activities contribute to an increased use of high quality fuel pellets for energy purposes in Europe in order to secure energy supplies and decrease emission of greenhouse gases. “Pellet for Europe” is partly funded by the European Commission ALTENER program. The objectives of the program are [4]:

- Stimulation of new wood pellet markets through facilitation of co-operation between market actors.
- Stimulation of new markets of pellets from agricultural residues through market studies and awareness campaigns.
- Support the development and integration of the European pellet market by providing technical and market information.

Pellets@las is the successor to the previous project – 'Pellets for Europe' which ran from June 2003 to April 2006. Pellets@las has inherited the website and database from this project and will update and improve it over the next two years. It contains information on all pellet actors, studies on pellets markets, statistics and best practices. 'Pellets for Europe' aimed to provide technical and market information for pellet market actors and to promote pellet technologies across Europe. The main aim for this European project was to support the development of the European pellet market. Another aim was to contribute to an increased use of high quality fuel pellets for energy purposes in Europe in order to secure energy supplies and decrease greenhouse gas emissions. Additional targets were to stimulate new markets in Southern Europe where the pellet market is still in its infancy and to take advantage of the wood and agricultural residues not already utilized there [5].

4.1. Biomass availability in Greece

The total biomass contribution, as primary energy, is presently estimated at 1 Mtoe/year [6], and can be considered as more-or-less, stable in the short run. In contrast to what is happening in most European countries, within the present bioenergy use in Greece, forest-derived woody biomass does not represent the dominant type of solid biofuel. Greek bioenergy is mainly based on agricultural–derived sources [6].

The current agricultural biomass resources in Greece are contributed as follows:

- Agricultural crop residues (straws, stalks, etc.).
- Agro-industrial residues (leaves, kernels, shells, rice husks).
- Forest biomass resources (firewood).
- Wood processing residues from industrial uses (sawdust).

4.2. Greek pellet market

The pellet market in Greece is in an initial state. Pellets are produced in considerable amounts, but domestic consumption is hardly developed. Pellets are only used in some industrial applications. Pellet trading within the country does hardly occur, but trade with other European markets is growing significantly [7].

Now days, the major raw material for pellet production is wood residues from wood industries (furniture producers, building materials, etc.). The current biomass availability covers the demand of the pellet industry, but if the Greek pellet market starts growing more rapidly, biomass availability will become a limiting factor rather soon. At the moment, large quantities of biomass are unused. With growing demand these raw materials will be considered as potential raw material for pellet production. In Greece, wood residues are used unprocessed, as they leave the industrial operation. These materials are often used in boilers directly by the producing company or by companies near the production site. Nowadays, with the development of wood pellet production, these residues become more important, which means that the economic profit of the company would be higher if residues were sold as raw material for pellet production [7].

Being at the beginning of its development, the Greek pellet market still features considerable growth potentials. In 2005, no pellet production activity was reported from Greece while, by the end of 2008, there were five pellet production companies. Two more producers will start their operation during 2009. Development of the pellets market over the past years is presented in Table 2 [7].

Table 1
Characteristics of a typical biomass pellet [8].

Parameters	Unit	Value
Diameter	Mm	6–10
Length	Mm	10–13
Energy content	MJ/kg	16.9–18
Moisture content	%	7–12
Ash content	%	2
Bulk density	kg/m^3	650–700
Space demand	m^3/tn	1.5

Table 2
Development of the pellet's market over the past years in Greece [7].

Year	Total production capacity [tn/year]	Total production [tn/year]	Consumption [tn/year]
2008	87,000	27,800	11,100
2007	72,200	26,000	5400

4.3. Legislative frame

There is no legislative framework for pellet production and consumption in Greece. The recent law on the Development of Renewable Energy Sources that the Greek Government applied (2005), does not promote biomass use for energy purposes (photovoltaic and wind energy are subsidized three times more than biomass), even though 80% of the Renewable Energy Sources in the European Union comes from biomass [7].

The Greek pellet market just started to develop. The first production plant started in late 2006 when there was no consumption in the country. However, during the last three years, six more producers appeared and the production showed rapid increase. It is obvious that in a virgin market there are always business opportunities, which was the reason for the development of these industries [7].

The main pellets plants in Greece are Maki S.A., Hellenic pellets, Bioenergy Hellas, Angelousis S.A., Sakkas A.E., Agrop, Asa Impoexpo energy, Light business development, Avea.

4.4. Greek pellets trade

All of the pellet producers provide sufficient pellet storage capacities at their plants. However, most of them do not store their final product, because the demand covers the production. At the moment, there is no household use of pellets and only minor use in industry. The producers focus on exports, mainly to Italy and always in big or small bags. The trade is always between the producer and retailer and the transportation is constantly being conducted by trucks on ferries (Igoumenitsa port to Ancona port). Most of the produced quantities are exported. 52.5% of the national production (one of the larger producers) is sold to a Greek trader, who is exporting the whole quantity to Italy. The total export amount for 2008 is 9600 tn and as there is hardly any domestic consumption there are no imports [7].

4.5. Pellets characteristics and prices

The typical pellets characteristics are presented in Table 1 [8]. Generally, we can say that prices for pellets have geographical variations and they are formed by the law of supply and demand in each country. However, according to recent research it is estimated that the price of pellets average from 100 to 120 €/tn for large

consumers (e.g. industries) and 150–200 €/tn for small-scale consumers (residential users). In addition, attention should be paid to prices CIF-ARA (cost, insurance and freight for pellets delivered to the Amsterdam/Rotterdam or Antwerp) which is the price of pellets, including insurance and freight charges for delivery in the areas of Amsterdam, Rotterdam and Antwerp, which are very important areas for international trade. These prices are higher in Greece and they reach the 190 €/tn [9].

5. Pellets production technology

Wood pellets are usually made from dry, untreated, industrial wood waste such as sawdust, shavings or ground wood chips. This material under high pressure and temperature is compressed into small pellets, cylindrical in shape. The manufacturing process is determined by the raw material but usually includes the following steps: reception of raw material, screening, grinding, drying, pelletizing, cooling, sifting and packaging [3].

Wood pellets are the product of a relatively simple mechanical process that relies on pressure to form wood fiber into a pellet. Fig. 1 provides the flow sheet of a typical pellet plant. The raw material arrives in a variety of partially processed states (chips, shavings, sawdust, stripped bark, etc.) from which it must be dried and ground into a uniform size. It does not matter what order the pre-processing steps of drying and grinding happen in. Once the raw material is dry and uniform in size, it is forced through a press under a very high pressure to create the pellet. Pellets are then cooled to allow the natural bonding agents to set. Once the pellets have hardened, any loose material is screened out and fed back into the pelletizing process. Pellets are then ready to be distributed to the market. The main steps in pelletization process are the following follows [3]:

- Feeding

  Managing the feedstock is one of the greatest areas of concern for a pelletizing facility. Raw materials have to be sourced locally because their low bulk density makes them too costly to transport over long distances [3].
- Drying

  Drying is a necessary part in the production of pellets. While some inputs, like planer shavings, do not need to be dried, most do. Drying consumes a large amount of energy. This raises concerns with the net energy value of wood pellets as a fuel source. Wood fiber can be pelletized at moisture contents as high as 17%. However, the optimal level is 12% or less if a final product with a moisture content of 6–8% is to be achieved. Raw materials can also be too dry to pelletize so finding the right balance between high and low moisture content raw materials is necessary. Drying is a focal point of research as the industry attempts to minimize costs and improve the quality of wood pellet energy [3].
- Grinding

  The grinding process is also known as milling. Material should be ground to a size no bigger than the diameter of the pellet (~6 mm) producing a substance with a consistency similar to bread crumbs. Raw material should be filtered before grinding to remove materials like stone or metal [3].
- Conditioning

  Many pelletizing machines come with a built-in steam conditioning chamber. Super-heated steam, at temperatures above 100° C (212 F), is used to soften the wood before it is compacted. Steam conditioning is not necessary but does make the raw material less abrasive to the pelletizing equipment. This helps reduce the maintenance costs [3].
- Pelletizing

  Pelletizing machines, also known as extruders, are available in a range of sizes. Generally, every 100 horsepower provides a capacity of approximately one tonne of pellets per hour. Pelletizing machines come in two common forms [3]:
  1. *Flat*: where raw material is pressed through the top of a horizontally mounted die.
  2. *Rotary*: where two (or more) rotary presses push raw material from inside a ring die to the outside where it can be cut into the desired length.

  Both systems create a pellet by using a great deal of pressure to force the raw material through holes in the die. As pressure and friction increase so does the temperature of the wood. This allows lignin to soften and the fiber to be reshaped into pellet form [3].
- Cooling

  The cooling process is critical to the pellets strength and durability. As pellets leave the extruder they are hot (90–95 °C) and soft. They are gradually air cooled, which allows the lignin to solidify and strengthen the pellets. In contrast to the drying process, cooling does not involve the addition of the energy. There are three types of coolers: vertical, horizontal and continuous flow [3].
- Screening

  Once pellets have cooled, they are passed over a vibrating screen to remove any fine material. These “fines” are augured back into the pelletizing process to ensure that no raw material is wasted. Screening ensures the fuel source is clean and as near to dust free as possible. Once screened, pellets are ready to be packaged for the desired end use [3].
- Distribution and storage

  Pellets can be distributed in bulk form, by truck, rail or ship or bagged in smaller quantities. Pellets can be purchased either bagged or in bulk and price can be calculated per total weight according to the moisture content [3].

Table 3
A comparison of biomass pellets and torrefied pellets (TOP) characteristics [8].

Characteristic	Biomass	Pellets	TOP pellets
Moisture content (%)	35	10	3
Calorific value (MJ/kg)	10.5	16	21
Mass density (bulk) (kg/m^3)	550	600	800
Energy density (GJ/m^3)	5.8	9	16.7

6. Modern technologies for improved pellet’s production

For the improvement of pellet production new methods have been developed recently.

6.1. Torrefaction

Torrefaction is a new technology to upgrade biomass for combustion and gasification applications. It is a thermal pre-treatment technology carried out at atmospheric pressure in the absence of oxygen. It occurs at temperatures between 200 and 300 °C where a solid uniform product is produced. This product has very low moisture content and a high calorific value compared to fresh biomass [8].

In the initial heating stage, biomass moisture content evaporation is very slow nonetheless, the biomass temperature increases. In the pre-drying stage, moisture content decreases dramatically while the biomass temperature stays constant. Following this stage, post-drying and intermediate heating occurs. The temperature increases up to 200 °C and the physically bounded water is released. Above 200 °C torrefaction reaction occurs. Devolatilization takes part in this stage. And finally, solid product is cooled to below

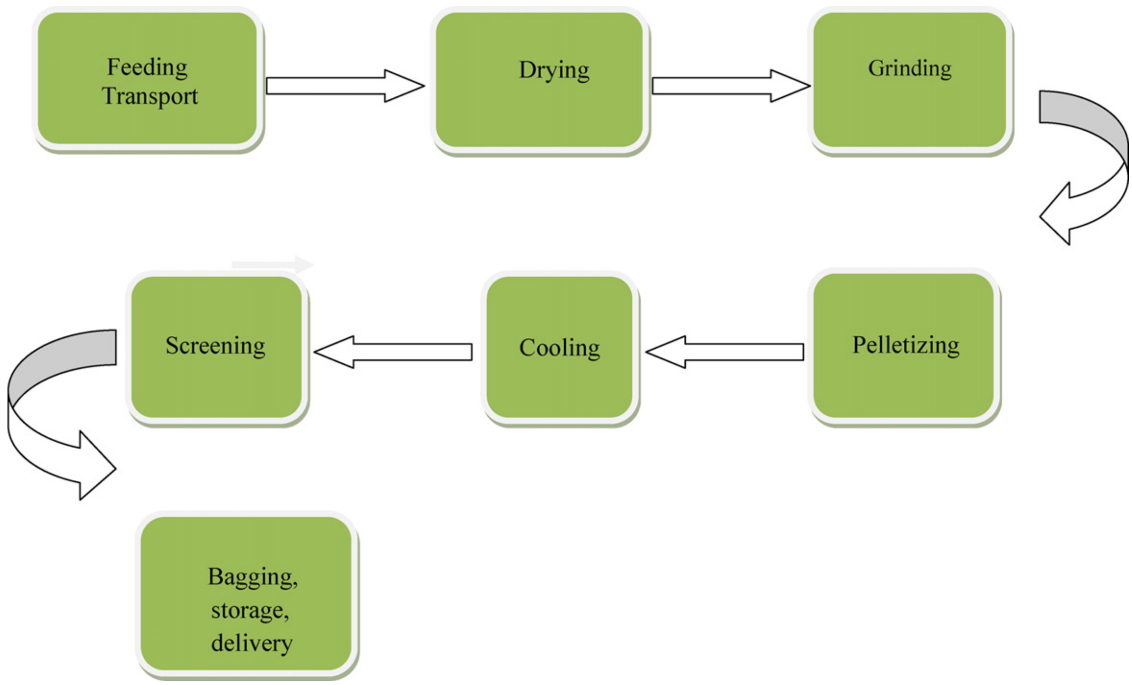


Fig. 1. The pelletizing process flow sheet.

Table 4
Cost-breakdown (in €/GJ) of pellet production in South-Africa and end-user application in NW-Europe [11].

Cost-breakdown (in €/GJ)	TOP process	Pelletization process
Feedstock	0.7	0.7
Pellet production	2.0	2.2
Logistics	1.8	2.9
Total	4.5	5.8

200 °C. In Table 3 a comparison between the properties of biomass, simple pellets and top pellets is presented [8].

A business case was developed to explore the economic advantages of TOP pellets over wood pellets. The cost breakdown of this business case is given in Table 4 and is based on pellet production in South Africa and sales to power stations in the North-West of Europe [10].

Although torrefaction process has many advantages, still the required technology that will make its introduction in biomass-to-energy chains economically justified is not yet mature.

6.2. Improved drying methods

Below improved methods for pellets drying are presented depending on the means and the temperature that is applied and the pre-treatment method of torrefaction.

Dryers can be classified according to the medium used in the drying process. In Sweden flue gas dryers and superheated steam dryers are used for commercial drying of sawdust. Rotary-drum dryers using combustion gases as the heating medium are the most common technique for drying sawdust in Sweden. Dryers investigated in this paper work as convection dryers where a gas both supplies the necessary energy and transports away the emitted steam. The superheated steam dryers have some key advantages compared to air dryers. No oxidation or combustion reactions are possible. Steam dryers have higher drying rates than air and gas dryers. Steam drying also avoids the danger of fire or explosions and allows toxic or valuable liquids to be separated in condensers. However, the systems are more complex and even a small steam leakage is devastating to the energy efficiency of the steam dryer [11].

The Renergi LTK Dryer system was developed to dry biofuels. The system consists mainly of a condenser and a low temperature dryer. The condenser makes it possible to transform waste energy and utilize that energy to preheat fresh air, which constitutes the drying medium. The air of the drying process has a temperature of 70 °C, meaning that it is a well-suited for drying of chips, sawdust, etc., since no hydrocarbons or other chemical contaminants are released. The gas can be emitted without advanced cleaning, assuming that any requirements on particle content are satisfied. The Renergi system generates significant profits. Either a fuel reduction on the order of 40–50% can be achieved, or productivity can be increased by up to 100% with retained fuel amounts [12].

6.3. Cold pelletizing process

A cold biomass pelletizing technology has been developed through the co-operation between Beijing Hui-Zhong-Shi Bio-Energy Company and Tsinghua University. This technology simplifies existing hot pelletizing technologies – does not need drying of raw materials which are naturally dried and extrusion. Therefore, the technology has the following advantages [13]:

1. Lower specific energy consumption and operation cost.
2. Less investment due to short production equipment close to production places of raw material, leading to lower transportation cost of raw materials and final products.

The above advantages are particularly applicable to circumstances in the vast rural areas of China [13].

7. Pellets as a solid fuel for energy production

Biomass pellet fuel can be an alternative source of heat for homes, businesses and commercial steam generation systems.

7.1. Combustion in furnace

Depending on the way how the pellets are fed into the furnace, three basic principles of wood pellet combustion systems can be distinguished: underfed burners, horizontally fed burners and overfed burners. In underfed (also called "underfeed stoker" or "underfeed retort furnace") and horizontally fed burners a so-called stoker screw feeds the fuel into the combustion chamber from below. Depending on the design, the flame burns horizontally (as for the horizontally fed burner) or upwards. In overfed burners the pellets conveyed from the storage tank by the conveying screw fall through a shaft into the glow zone at the grate. An advantage of this system is that a very accurate dosing of pellets according to the current power demand is achieved. A disadvantage is the impact of the falling pellets on the glowing bed of embers, leading to an increased entrainment of dust and unburned particles as well as to unsteady combustion behavior on the grate. The separation of the feeding when the furnace is turned off [14].

Depending on the pellet burner design, two basic principles of pellet burners can be distinguished: retort furnaces and grate furnaces. Pellet grate furnaces can additionally be split in fixed grate, hinged grate and step grate systems. Retort furnaces are always designed as underfed burners. Grate furnaces are designed as horizontally or overfed burners [14].

7.2. Combustion in a small domestic boiler

A study has performed [15] on a 13 kWh commercial domestic boiler using pellets as fuel by an Austrian researcher. Four different types of pellets were used and, for each one, the boiler was tested as a function of its capacity and the fan regulation affecting excess air. Measurements were performed for boiler heat load, pellets consumption rate, flue-gas temperature and composition. Mass balances allowed the calculation of the flue-gas flow rate and associated heat losses. Losses from incomplete combustion have also been quantified. Under boiler steady-state conditions the flue-gas O_2 concentration changes with boiler load and ventilation due to the regulation scheme of the boiler. Flue-gas CO shows a minimum for values of O_2 in the flue-gases of about 13%. NO_x emissions are independent of excess air for low values of nitrogen in the fuel whereas, for larger values, NO^* emissions increase with the O_2 present in the combustion products. The fractional conversion of the pellets nitrogen into NO_Λ is in line with literature data. The boiler start-up was characterized by the temperature evolution inside and above the bed showing the propagation of combustion in the bed during about 10 min. During boiler start-up, a maximum in CO emissions was observed which is associated with the maximum combustion intensity, as typified by the flue-gas O_2 concentration and temperature, regardless the pellets type [15].

A pellets' boiler was tested with four different types of pellets showing a similar thermal performance with boiler efficiencies up to 77%. Unburnt heat losses were higher for pellets with a mean diameter larger than the one recommended for the present boiler [15].

CO emissions, under steady-state conditions, were, in most cases, below 1500 mg/Nm^3, with minimum values being achieved for O_2 concentrations in the flue-gases around 13%. NO_Λ-emissions, under boiler steady-state conditions, correlate well with both excess air and pellets nitrogen content [15].

Boiler start-up has been characterized in terms of combustion temperature and emissions. Maximum CO concentrations up to 1.5% were observed and found to depend on the combustion intensity [15].

8. Factors affecting strength and durability of densified biomass products

Effectiveness of a densification process to create strong and durable bonding in densified products such as pellets, briquettes, and cubes can be determined by testing the strength (compressive resistance, impact resistance, and water resistance), and durability (abrasion resistance) of the densined products. These tests can indicate the maximum force/stress that the densified products can withstand, and the amount of fines produced during handling, transportation, and storage. In this study, the procedures used for measuring the strength and durability of the densified products are discussed. The effects of constituents of the feed such as starch, protein, fiber, fat, lignin and extractives; feed moisture content; feed particle size and its distribution; feed conditioning temperature/preheating of feed; added binders; and densification equipment variables (forming pressure, and pellet mill and roll press variables) on the strength and durability of the densified products are reviewed. This study helped to select process parameters to produce strong and durable densified products from new biomass feedstocks or animal feed formulations [16].

Densification of biomass materials into pellets, briquettes, or cubes could reduce costs and problems with handling, transportation, storage, and utilization of low bulk density biomass materials. To produce good quality (i.e., high strength and durability) densified products from biomass feedstocks whose densification characteristics are unknown, directions or ways to make strong and durable densified products are needed. From this case study the following conclusions could be drawn [16]:

- Factors related to the feedstock (starch, protein, fiber, fat, lignin and extractives, moisture content, and particle size and its distribution), pre-conditioning processes (steam conditioning/preheating, and addition of binders), and densification equipment (forming pressure, and pellet mill and roll press variables) would affect the strength and durability of the densified products. Due to the interactions of the above densification factors (variables) affecting the strength and durability of the densified products, the optimum densification variables may need to be determined using an optimization procedure. Also, post-production conditions such as cooling/drying and high humidity storage conditions would influence the strength and durability of the densified products.
- Generalized optimum conditions related to the feed material, pre-conditioning processes, and densification equipment were established for manufacturing high quality densified products by pelletizing, briquetting or cubing.
- There is a need to develop standards on the minimum acceptance levels for the strength (i.e., compressive resistance, impact resistance, and water resistance), and durability (i.e., abrasive resistance) of the densified products made from biomass feedstock and animal feeds in the U.S. Guidelines for developing such standards are discussed [16].

9. Pyrolysis of mixed biomass pellets for liquid biofuel production

Pyrolysis is a thermochemical method to use pellets as fuel. The products of pellet pyrolysis are liquid, gas and char, and can be used as fuel or into a source of higher value products; the first one if treated properly for the production of biodiesel and the second for energy production [17]. Char may be useful as a fuel, either directly (briquettes) or as char-oil and char-water slurries and also in activated carbon production. Virtually, charcoal is the carbon derived

from photosynthesis, which is why its use as a soil amendment sequesters carbon and reduces the greenhouse gas [17]. Except of wood pellets, mixed biomass pellets are also challenging.

Mixed biomass pellets (MBP) have a great potential in enlarging the use of biomass for energy conversion, particularly in central and south European countries. With the exhaustion of biomass residues for wood pellets production (particularly sawdust) the production of MBP is of increasing interest for project developers and biomass producers. Hence, in this market not the availability of the biomass resource is the most critical factor, but the availability of a sales market itself. A study was conducted by our group on pyrolysis of mixed biomass pellets [17].

Pelletization of a combination of wood with corn (sample 1), and wood with cotton (sample 2) have been accomplished in this study, followed by pyrolysis of both samples. As corn and cotton residues are two types of biomass which is available in large quantities in Greece, the ultimate aim was to investigate the possibility this type of pellets to be used as biofuels or for carbons with high absorbent capacity [17]. Fig. 2 shows the LHV values obtained of the pyrolysis gas from mixed pellets from wood with corn and wood with cotton respectively.

The biomass pellets used in the experiments of this study were composed (a) of 50% wood (25% pine, 25% fir) and 50% corn (sample 1) and (b) 50% wood (25% pine, 25% fir) and 50% cotton (sample 2) [17].

The experiments for corn stalk were carried out in the temperature range 400–750 °C, at atmospheric pressure in He (50 ml/min), with a heating rate 65 °C s^{-1} for the first sample and 75 °C s^{-1} for the second. The products included char, gas and volatile compounds [17].

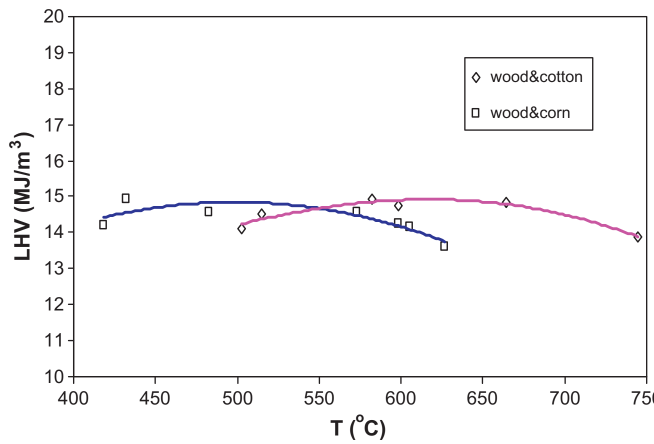


Fig. 2. LHV of mixed biomass pellets pyrolysis gas.

The study concerned the rapid pyrolysis of biomass pellets (wood with corn and cotton) at 400–750 °C, performed in wire mesh reactor in a laboratory scale at atmospheric pressure. All three products of the pyrolysis of these two samples can be utilized; gas and liquid for biofuels, and char for the production of high added value by-products. The gas products contained high amounts of CO and H_2, while the concentration of CO_2 was low, especially comparing with combustion treatment. In addition, from gas composition the heating value of gas has been determined (14–15 MJ m^{-3}) and it can be said that both pellet samples seem to be suitable for energy production because of their energy

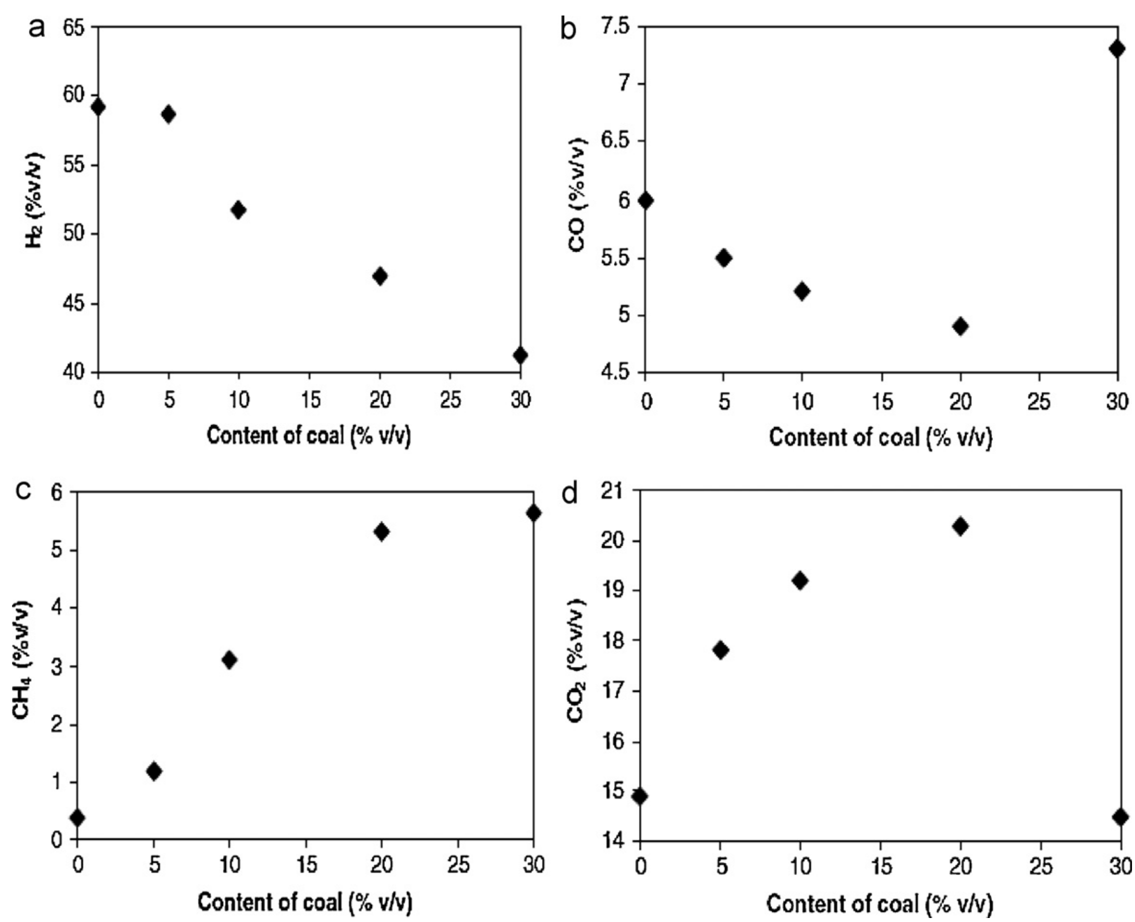


Fig. 3. Effect of the content of coal over the (% v/v) composition: (a) H_2, (b) CO, (c) CH_4 and (d) CO_2 [19].

content. Having also high amounts of liquids the specific samples are recommended to be studied with proper set up for biodiesel production. The char that remained after pyrolysis is proposed to be studied for the production of activated carbon [17].

10. CO-gasification of pelletized wood residues

In order to study the process of CO-gasification of pelletized wood residues, cylindrical pellets 8 mm in length and 4 mm in diameter were used. These ones were made by a blend of Pinus Patula and Cypress sawdust and coal in proportions of 0%, 5%, 10%, 20%, and 30% v/v of coal of rank sub-bituminous extracted from the Nechν mine (Amagα-Antioquia). For this procedure, sodium carboxymethyl cellulose (CMC) was used as binder at three different concentrations. The co-gasification experiments were carried out with two kinds of mixtures, the first one was composed of granular coal and pellets of 100% wood and the second one was composed of pulverized wood and granular coal pellets. All samples were co-gasified with steam by using an electrical heated fluidized-bed reactor, operating in batches, at 850 °C [18].

The most important gaseous products identified and quantified in the procedure of the co-gasification of wood and coal pellets are graphically shown in Fig. 3. The results in Fig. 3 show how an increase in the quantity of coal in the pellets has a negative effect over the content of hydrogen in the gaseous product. The effect over the quantity of carbon monoxide is different because a curve is formed with a minimum value nearing 20% of coal, according to Fig. 3b. This behavior is contrary to the tendency already shown by carbon dioxide which reveals a maximum of evolution at around 20% of coal, according to Fig. 3d. The effect of the content of coal over methane production (methanization reaction) is upward sloping during the entire interval, which somehow indicates that some of the H_2 is consumed during its production and the behavior in the evolution of CO_2 and CO seem to complement one another. In other words, in the production of CO_2 the consumption of CO in a (0–20%) interval is probably caused by its reaction to steam, the water–gas shift reaction; which increases in the same interval as that of the content of coal and vice versa, for coal percentages of over 20% [18].

By comparing Fig. 3a and c, it can be concluded that H_2 decreases as the percentage of coal increases favoring the methane formation, however, maybe this increase is a reflection of direct production of methane from the increasing coal content via pyrolysis. It is important to highlight that even though an increase in the concentration of CH_4 can be observed, it is also clear that its concentration during the entire interval is relatively low since its formation reactions are favorable at pressures above atmospheric pressure [18].

In Fig. 4, the evolution of the most important components from the co-gasification of mixtures composed of granular coal and pellets of 100% wood is graphed. In Fig. 4a and b, Fig. 4a decreasing evolution of H_2 and CO, respectively can be observed throughout the entire interval of coal content, and at the same time an increase of CH_4 but with contents no higher than 2.5%. CO_2 presents a parabolic shape in its evolution, with a maximum at a value close to 20% of coal [18].

By comparing the results obtained from the co-gasification of the pellets composed of pulverized wood and granular coal to those obtained from the mixtures composed of granular coal and pellets of 100% wood, similar behaviors can be observed in the evolution of H_2 and CO_2, but not in that of CH_4 and CO. It is evident that the different ways in which the biomass and coal were mixed together, in both cases, considerably affected the evolution of carbon monoxide. When pellets are composed of wood/coal in a same matrix, the contact between both materials is much more intimate, and because the wood in the pellet has a greater volumetric (or spatial) proportion, the reaction of some of those coal particles hidden within said matrix can be delayed which somehow affects the formation reaction of the CO. For coal that is not part of the binded biomass, the competition between the reactions of coal and those of the biomass are more direct, causing a different effect over the reaction mechanisms of the CO in comparison to the previous case [18].

11. Economic aspects

Comprehensive investigations and calculations of the production costs of wood pellets under consideration of all relevant parameters and for different framework conditions have been performed within the EU-ALTENER project "An Integrated European Market for Densified Biomass Fuels (INDEBIF)". The calculations are based on data from planned and already realized pellet production plants. Furthermore, data obtained from a questionnaire survey of producers of wood pellets in Austria, South Tyrol and Sweden has been considered for the calculation of the production costs [19].

The following parameters must be considered in a detailed calculation of the pellet production costs [19]:

- The investment costs of all units of the pellet production process as well as of construction, offices and data processing, market introduction and planning as well as the utilization period and maintenance costs of all units and facilities.
- The raw material costs as well as the water content and the bulk density of the raw material used.
- The price for electricity, the electrical power required for all electrical installations and a simultaneity factor, which considers the fact that not all electrical installations operate on full load at the same time.
- The interest rate.
- The equipment availability, which considers both scheduled and unscheduled shutdowns.
- In case a preceding dryer is installed at the start of the process line, the specific heat costs and the heat demand for drying, furthermore the recoverable heat and the profit from heat sales in case that heat recovery takes place.
- The costs and the demand on bio-additives that may be used and the corresponding dosing system.
- If a conditioning unit working with steam is used, the demand and the costs of the steam.
- The storage costs, depending on the storage capacity and the kind of storage system used (storehouse and/or silo storage).
- The kind of shift work operated (plant utilization).
- The personnel cost both in production, marketing and administration.
- The annual pellet production rate as well as the water content and the bulk density of the pellets produced.
- Other costs.

From these data both the total pellet production costs as well as the operating of the pelletization process can be calculated.

The calculations for Austrian framework conditions show that economic wood pellet production is possible both in small-scale (production rates of some hundred tonnes per year) as well as in large-scale plants (production rates of some 10,000 tn/year). However, for small-scale units in particular it is very important to take care of the specific framework conditions of the producer, because the risk of a non-economic pellet production is substantially higher than for large-scale systems. For economic reasons, the use of dryers in small-scale pellet production plants cannot be recommended [19].

The main cost factors are the drying costs (if wet raw material is used), followed by the raw material costs. The pelletization

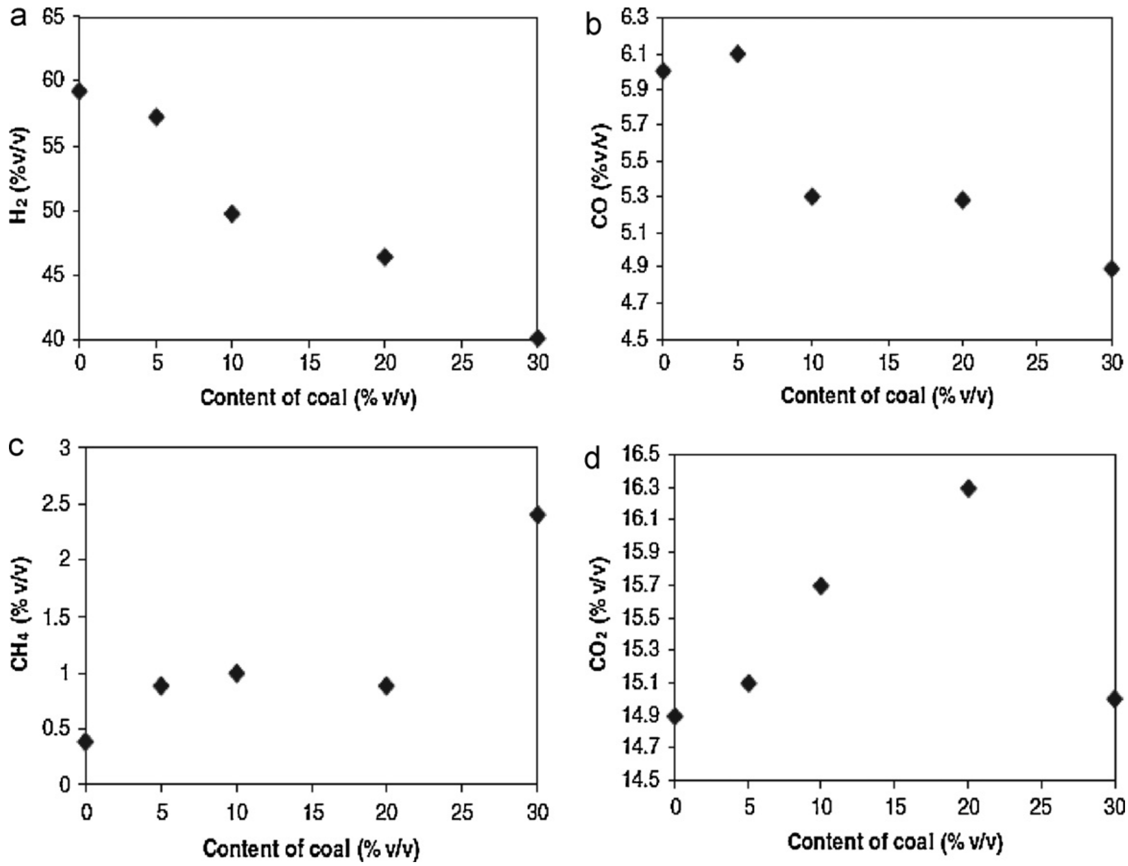


Fig. 4. Mixed pellets of biomass and coal. Effect of the content of coal over the (% v/v) composition: (a) H_2, (b) CO, (c) CH_4 and (d) CO_2 [19].

itself and personnel costs are also of great relevance. Moreover, the pellet production costs are strongly influenced by the plant utilization. The direct comparison of typical pellet production costs in Austria and Sweden shows the Swedish pellet production costs to be considerably lower. The main reasons for this result are the larger plant capacity (economy-of-scale effect) and an efficient heat recovering system from the dryers usually applied in Sweden. Another difference is the price of electricity, which is in general much lower in Sweden. If the drying costs were assumed to be the same, the difference between the total pellet production costs would be reduced from about one third to about 19%. Possibilities to reduce the pellet production costs in Austria could therefore be increased plant capacities and the combination of decentralized biomass CHP plants or biomass district heating plants with pellet production plants in order to reduce the drying costs. A substantial reduction of the electricity price in Austria is not realistic. The combination of decentralized biomass CHP plants with pellet production plants in Austria is an economically and ecologically very interesting solution for future applications (provided that the pellet production plant uses wet raw material with drying demand), due to the facts that heat production and heat consumption can be optimally adjusted, that the heat for drying is also produced from biomass and that high feed-in tariffs for green electricity are valid in Austria [19].

12. Discussion and guidelines for Greece

The analysis that proceeded has provided the following conclusions and reflections in regard to the prospects that are opened and the problems that can exist in the Greek pellet market:

- Greek investors could give attention to a dynamic entry in the international pellet market, where they can ensure the disposal of product in the permanently developing European and world market in very competitive prices.
- The economic analysis of pellets production investments proved the viability of productive units. The production efficiency found high.
- The exploitation of available raw material for the pellets production will contribute substantially in the rationalization of management of the forestry and rural extents simultaneously with the management of remains the forestal and rural industries, involving important economic profits for those who are activated in those sectors.
- Deliberate is judged the collaboration between local governors aiming at the aid and the promotion of pellets in Greece. The use of testimonial “clean energy”, the benefit of motives, the improvement and aid of energy infrastructures, the informative expeditions, etc. can contribute in the growth a consuming and political conscience friendly to the use of pellets.
- Finally, the research efforts about the possibility of disposal in the Greek and world market pellets must be growth so that exist quantified objectives and forecasts in regional and national level. The research should be combined with the effort of a qualitative and efficient product with application of innovative processes and methods in all stages concerning the circle of life of product.
- The biomass availability is an important factor, but it has to be mentioned that a big percentage is not being used for energy purposes and remains unused. The responsible authorities have to be activated and try to calculate the exact availability and its possible use. Greek citizens do not have adequate information on other energy sources than the conventional ones and cannot act alone. It is important to promote new energy technologies, in order to

make pellets a part of peoples live. Mechanisms ensuring the production of qualitative products, with standardized/certified characteristics are needed to be developed.

- Their price is from the lowest in Europe. This fact, in combination with the minimal industrial units of production in our country and generally in south Europe, gives the opportunity for the growth of this economic activity, in our country too. However, are required the combination of undertaking of private initiatives and the benefit of motives from the political side.

13. Conclusions

Pellets are friendly to the environment, proposal of alternative form of fuels, and with important finances competitive advantages. Moreover they constitute one of the most promising forms of energy that can contribute in the achievement of objectives that place the Community directives and international conditions in regard to the production and use of renewable sources of energy.

They are transported and stored easily because of the form and their size. That's the reason why pellets are preferred as fuel concerning others, which are produced by biomass and are not sold in the consumer with concrete characteristics of quality.

They constitute a very promising form of bio-fuel, which is responding in the needs of domestic market, mainly with regard to domestic users but also in wider scale consumers, as industries, having crowd of applications.

The pellet market in Greece is not well developed, but it has potential. However, if the proper actions are taken, the expansion of the market is sure. The biggest issue to be solved is the legislative aspect of pellets. The RES development law is now being renewed and promoting biomass energy production. There is a significant demand for Greek pellet standardization in order to improve its position in the global market in terms of quality.

References

[1] Sikkema R, Steiner M, Junginger M, Hiegl W. Development and promotion of a transparent European Pellets Market Creation of a European real-time Pellets Atlas. Final report on producers, traders and consumers of wood pellets. Wood pellets data collection Deliverable 4.1/4.2/4.3 for the Pellets@las project; 2009. www.forcebioenergy.dk/pelletsatlas_docs/showdoc.asp?id=100113154336&type=doc&pdf=true [07.10.10].

[2] Verma V, Bram S, De Ruycfe J. Small scale biomass heating systems: standards, quality labelling and market driving factors – an EU outlook. Biomass and Bioenergy 2009;33(10):1393–402.

[3] Peksa-Blanchard M, Dolzan P, Grassi A, Heinimö J, Junginger M, Ranta T, et al. Global wood pellets markets and industry: policy drivers, market status and raw material, Potential IEA Bioenergy Task 40; 2007. http://www.bioenergytrade.org/downloads/ieatask40pelletandrawmaterialstudynov2007final.pdf [03.12.09].

[4] Karapanagiotis N."Συσσωματώματα για την Ευρώπη" Πρόοδος και αποτελέσματα του έργου. Pellets for Europe; 2005 [in Greek]. http://www.cres.gr/pellets/index_files/pdf/17_05_05/3.pdf [25.09.09].

[5] Pellets@las. The PELLETS@LAS project. http://www.pelletsatlas.info/cms/site.aspx?p=9094 [14.10.09].

[6] Pigaht M, Janssen R, Passalacqua F, Zaetta C, Vegas L, Karapanagiotis N. Trends in pellets utilisation: prospects and reasons for variations in Italy, Spain and Greece. ALTENER Pellets for Europe Contract 4.1030/C/02-160. Task 3.2.1, Deliverable 17 (trends analysis); 2003. http://www.cres.gr/pellets/index_files/pdf/D17_Trends_analysis_2003_12_17a.pdf [05.01.10].

[7] Voulgaraki S, Balafoutis A, Papadakis G. Development and promotion of a transparent European pellets market creation of a European real-time pellets atlas. Pellet market country report Greece; 2009. http://www.pelletcentre.info/pelletsatlas_docs/showdoc.asp?id=091022153754&type=doc&pdf=true [12.02.10].

[8] Uslu A, Faaij APC, Bergman PCA. Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. Energy 2008;33(8):1206–23.

[9] Dallos G, Trigas M, Papadopoulos I, Sideras A. Wood pellets: the alternative energy source, EPIPLEON (37);2008 [in Greek]. http://www.wfdt.teilar.gr/papers/epipleon/81_Trigkas_kai_Papadopoulos_ka_Wood_pellets_EPIPLEON.pdf [12.11.09].

[10] Bergman P, Kiel J. Torrefaction for biomass upgrading. In: 14th European biomass conference & exhibition. 2005.

[11] Stahl M, Granstrom K, Berghel J, Renstrom R. Industrial processes for biomass drying and their effects on the quality properties of wood pellets. Biomass and Bioenergy 2004;27(6):621–8.

[12] Granstrand L. Increased production capacity with new drying system. In: 2nd World conference on pellets. Proceedings pellets. 2006.

[13] Dingkai Z, Peihua W. Development and characteristics of a cold biomass pelletizing technology in China. In: 2nd World conference on pellets. Proceedings pellets. 2006.

[14] Obernberger I, Thek G. Recent developments concerning pellet combustion technologies – a review of Austrian developments. In: 2nd World conference on pellets. Proceedings pellets. 2006.

[15] Dias J, Costa M, Azevedo J. Test of a small domestic boiler using different pellets. Biomass and Bioenergy 2004;27(6):531–9.

[16] Kaliyan N, Vance Morey R. Factors affecting strength and durability of densined biomass products. Biomass and Bioenergy 2009;33(3):337–59.

[17] Zabaniotou A, Ioannidou O. Thermochemical conversion of biomass pellets. In: Colloquium on 'Production and uses of Biofuels, PRORAES SMART INTERREG IIIC. 2006 [in Greek].

[18] Alzate C, Chejne F, Valdés C, Berrio A, De La Cruz J, Londoño C. CO-gasification of pelletized wood residues. Fuel 2008;88(3):437–45.

[19] Thek G, Obernberger I. Wood pellet production costs under Austrian and in comparison to Swedish framework conditions. Biomass and Bioenergy 2004;27(6):671–93.